

539,611

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property  
Organization  
International Bureau



17 JUN 2005

(43) International Publication Date  
8 July 2004 (08.07.2004)

PCT

(10) International Publication Number  
**WO 2004/057246 A1**

(51) International Patent Classification<sup>7</sup>: **F25B 9/00**, 49/02

(21) International Application Number:  
PCT/NO2003/000425

(22) International Filing Date:  
17 December 2003 (17.12.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
20026232 23 December 2002 (23.12.2002) NO

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(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

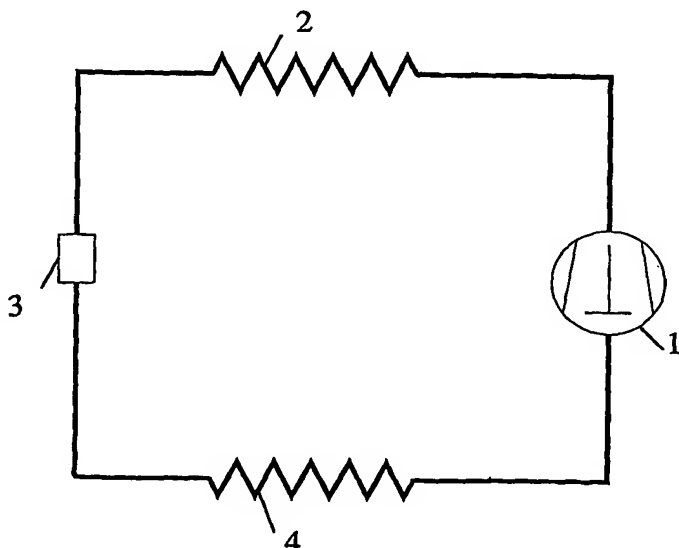
(84) Designated States (regional): ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD OF OPERATION AND REGULATON OF A VAPOUR COMPRESSION SYSTEM



(57) Abstract: A compression refrigeration system includes a compressor (1), heat rejector (2), expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure.

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**Method of operation and regulation of a vapour compression system****Field of invention**

The present invention relates to compression refrigeration system including a compressor, a heat rejector, an expansion means and a heat absorber connected in a closed circulation circuit that may operate with supercritical high-side pressure, using carbon dioxide or a mixture containing carbon dioxide as the refrigerant in the system.

**Description of prior art and background of the invention**

Conventional vapour compression systems reject heat by condensation of the refrigerant at subcritical pressure given by the saturation pressure at the given temperature. When using a refrigerant with low critical temperature, for instance CO<sub>2</sub>, the pressure at heat rejection will be supercritical if the temperature of the heat sink is high, for instance higher than the critical temperature of the refrigerant, in order to obtain efficient operation of the system. The cycle of operation will then be transcritical, for instance as known from WO 90/07683. Temperature and the high-pressure side will be independent variables contrary to conventional systems.

WO 94/14016 and WO 97/27437 both describe a simple circuit for realising such a system, in basis comprising a compressor, a heat rejector, an expansion means and an evaporator connected in a closed circuit. CO<sub>2</sub> is the preferred refrigerant for both of them.

The system coefficient of performance (COP) for trans-critical vapour compression systems is strongly affected by the level of the high side pressure. This is thoroughly explained by Pettersen & Skaugen (1994), who also presents a mathematical expression for the optimum pressure. Based on the fact that the high side pressure is independent from temperature, high side pressure can be controlled in order to achieve optimum energy efficiency. The next step is to determine optimum pressure for given operating conditions.

Several publications and patents are published, which suggests different strategies to determine the optimum high side pressure. Inokuty (1922) published a graphic method already in 1922, but it is not applicable for the present digital controllers.

EP 0 604 417 B1 describe how different signals can be used as steering parameter for the high side pressure. A suitable signal is the heat rejector refrigerant outlet temperature. The relation between optimum high side pressure and the signal temperature is calculated in advance or measured. Densopatent describes more or less an analogous strategy. Different signals are used as input parameter to a controller, which based on the signals regulates the pressure to a predetermined level.

Among others, Liao & Jakobsen (1998) presented an equation, which calculates optimum pressure from theoretical input. The equation does not take into account practical aspects which may affect the optimum pressure significantly.

Most methods for optimum pressure determination described above, has a theoretical approach. This means that they are not able to compensate for practical aspects like varying operating conditions, influence of oil in the system, ... Optimum pressure will then most probably be different from the calculated one. There is also a risk for a "wind up" and lack of control. The temperature signal gives a feedback to the controller, which adjust the pressure with some delay. If conditions change quit rapidly, the controller will never establish a constant pressure, and cooling capacity will vary.

As explained above, it is a possibility to run tests and measure optimum high side pressure relations. But this is time consuming, expensive. Furthermore, it is hard, if not impossible, to cover all operating conditions. And the measurements has to be performed for all new designs.

### **Summary of the invention**

*A major object of the present invention is to make a simple, efficient system that avoids the aforementioned shortcomings and disadvantages.*

*The invention is characterized by the features as defined in the accompanying independent claim 1.*

*Advantageous features of the invention are further defined in the accompanying independent claims 2–8.*

The present invention is based on the system described above, comprising at least a compressor, a heat rejector, an expansion means and a heat absorber. It is a new and novel method for optimum operation of such a system with respect to energy efficiency.

When operating conditions change, the controller in the trans-critical vapour compression system can perform a perturbation of the high side pressure and thereby establish a correlation between the pressure and the energy efficiency, or a suitable parameter reflecting the energy efficiency. A relation between high side pressure and energy efficiency can then easily be mapped, and optimum pressure determined and used until operating conditions change. This is a simple method which will work for all designs of trans-critical vapour compression systems. No initial measurements have to be made, and practical aspects will be accounted for on site.

#### **Brief description of the drawings.**

The invention will be further described in the following by way of examples only, and with reference to the drawings in which,

Fig. 1 illustrates a simple circuit for a vapour compression system.

Fig. 2 shows a temperature entropy diagram for carbon dioxide with an example of a typical trans-critical cycle.

Fig. 3 shows a schematic diagram showing the principle of optimum high side pressure determination. Temperature approach is used as COP reflecting parameter in the figure.

### Detailed description of the invention

Fig. 1 illustrates a conventional vapour compression system comprising a compressor 1, a heat rejector 2, an expansion means 3 and a heat absorber 4 connected in a closed circulation system.

Figure 2 shows a trans-critical CO<sub>2</sub> cycle in a temperature entropy diagram. The compression process is indicated as isentropic from state a to b. The refrigerant exit temperature out of the heat rejector c is regarded as constant. Specific work, specific cooling capacity and coefficient of performance are explained in the figure.

As mentioned above, there is a mathematical expression for high optimum high side pressure in a trans-critical vapour compression system. The expression is as follows:

$$\left( \frac{\partial h_c}{\partial p} \right)_\tau = -\varepsilon \left( \frac{\partial h_b}{\partial p} \right)_s$$

The optimum pressure is achieved when the marginal increase of capacity (change of  $h_c$  at constant temperature) equals  $\varepsilon$  times the marginal increase in work (change of  $h_b$  at constant entropy).

Perturbation of the high side pressure, is in principle a practical approach to use the equation above. By mapping the energy efficiency, or a parameter which reflects the energy efficiency, as function of high side pressure, it is possible to establish the point where the marginal increase of capacity equals  $\varepsilon$  times the marginal increase in work.

Various parameters can be used as reflection for the energy efficiency.

### Example 1

The temperature difference between refrigerant and heat sink at the cold end of the heat rejector 4, is often denoted as “temperature approach” for a trans-critical cycle. There is a correlation between high side pressure and the temperature approach. An increase of the high side pressure will lead to a reduction of temperature approach. The high side pressure can favourably be increased until a further increase does not lead to a significant reduction of temperature approach. At this point, optimum high side pressure is then in practice established, and the system can be operated at optimum conditions, maximizing the system COP. This principle is illustrated in figure 3.

A perturbation of the high side pressure will produce a relation as indicated in figure 3. When operating conditions change, or for other reasons, a new perturbation can be made and a new updated relation established. In this way, the trans-critical system will always be able to operate close to optimum conditions.

### Example 2

Instead of using the temperature approach, it is an option to use the gas cooler outlet temperature as parameter for reflection of energy efficiency.

### Example 3

By online measurements of system pressures and temperatures, it is possible to automatically calculate the enthalpies for a trans-critical cycle at the points 1 to 4 indicated in figure 2, if the refrigerant properties can be provided from property a library. The enthalpies can be used for calculation of the system coefficient of performance. A perturbation of the high side pressure will then produce a relation between COP and the high side pressure directly.

If COP is used as steering parameter, the optimum high side pressure will be established directly. If a COP reflecting parameter is used, an exact measure for the “marginal effect” on the parameter has to be quantified. This measure can however easily be estimated. Another possibility is to increase pressure until the parameter reaches a predetermined level.

### Claims

1. A compression refrigeration system including at least a compressor (1), a heat rejector (2), an expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure, **characterized** in that an online estimation of coefficient of performance (COP) , or a parameter reflecting the COP, can be used as a signal for optimum regulation and operation of the compression refrigeration system.
2. System according to claim 1, **characterized** in that carbon dioxide or a refrigerant mixture containing carbon dioxide is applied as the refrigerant in the system.
3. System according to any of the preceding claims 1-4, **characterized** in that a regulation system may vary pressure on the high pressure side in order to map the COP or the COP reflecting parameter as function of pressure for a given operation condition.
4. System according to any of the preceding claims 1-3, **characterized** in that the temperature difference between the refrigerant and heat sink at the cold end (temperature approach) can be used as a signal for optimum regulation and operation of the compression refrigeration system.
5. System according to any of the preceding claims 1-4, **characterized** in that pressure on the high pressure side of the system can be increased until the increase has marginal effect on the temperature approach.
6. System according to any of the preceding claims 1-5, **characterized** in that pressure on the high pressure side of the system can be increased until temperature approach is equal or lower than a predetermined level.

7. System according to the preceding claims 6, **characterized** in that the predetermined level may vary with varying operation conditions.
8. System according to the preceding claims 1-7, **characterized** in that the heat rejector outlet temperature can be used as COP reflecting parameter.



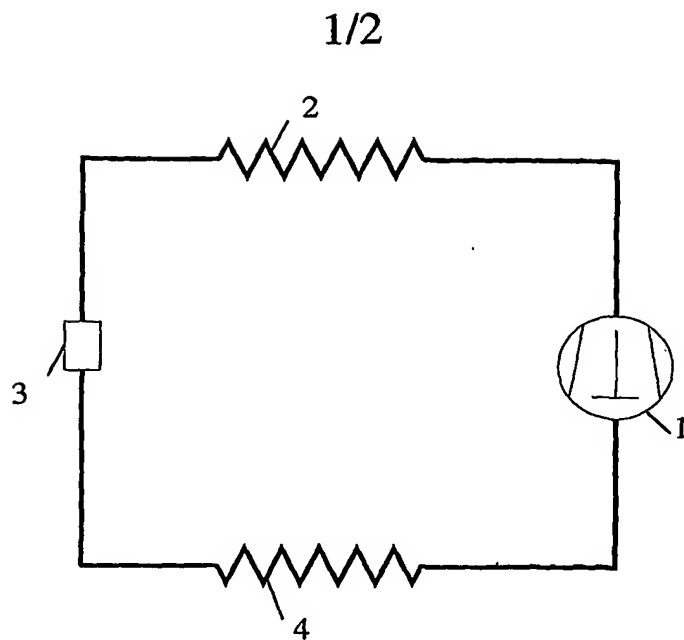


Fig. 1

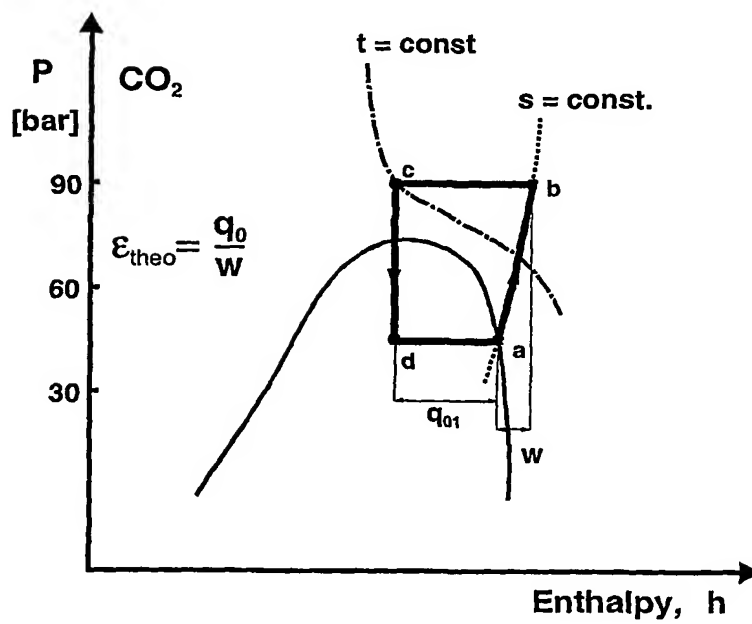


Fig. 2

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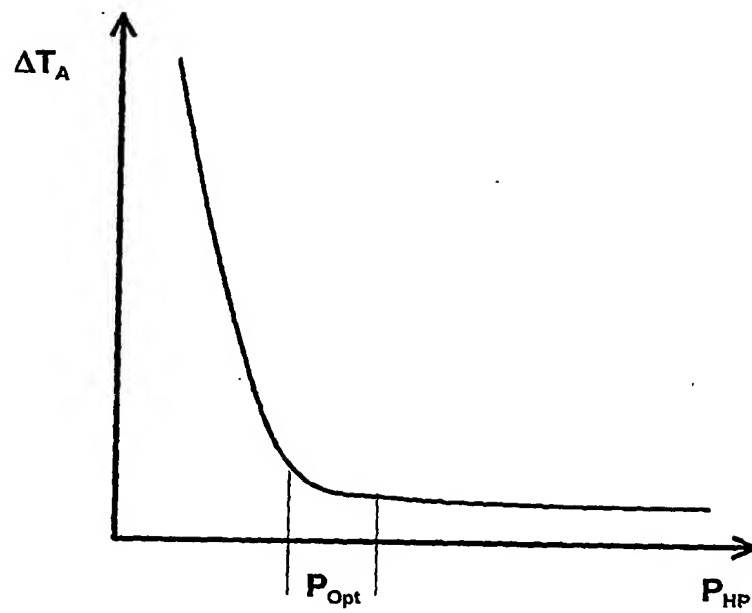


Fig. 3

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO 2003/000425

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F25B 9/00, F25B 49/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F25B, B60H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1202004 A1 (CALSONIC KANSEL CORPORATION), 2 May 2002 (02.05.2002), column 7, line 40 - column 9 --	1
X	DE 10053203 A1 (DENSO CORP., ET AL), 7 June 2001 (07.06.2001), column 1, line 23 - column 2, line 6, claim 1 --	1
X	DATABASE WPI Week 200206 Derwent Publications Ltd., London, GB; Class Q66, AN 2002-045403 & JP 2001289537 A (MITSUBISHI JUKOGYO KK), 19 October 2001 (2001-10-19) abstract --	1

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "B" earlier application or patent but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

9 March 2004

Date of mailing of the international search report

05-04-2004

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International application No.

PCT/NO 2003/000425

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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